PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

| (51) International Patent Classification 6 : E21B 23/00, 23/04, 4/18 | A1 | (11) International Publication Number: WO 98/01651<br>(43) International Publication Date: 15 January 1998 (15.01.98) |
|---|---|---|

(21) International Application Number: PCT/GB97/01868

(22) International Filing Date: 3 July 1997 (03.07.97)

(30) Priority Data:
08/675,176 3 July 1996 (03.07.96) US

(71) Applicants (*for all designated States except US*): CTES, L.C. [US/US]; 9870 Pozos Lane, Conroe, TX 77303 (US). LUCAS, Brian, Ronald [GB/GB]; 135 Westhall Road, Warlingham, Surrey CR6 9HJ (GB).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): NEWMAN, Kenneth, Ray [US/US]; 9630 Rancho Drive, Willis, TX 77378-6625 (US). HAVER, Nelson, Alan [US/US]; 4023 E. Mossey Oaks Road, Spring, TX 77389 (US). SPELLER, David, Joseph [US/US]; 7710 Highland Farms Road, Houston, TX 77095 (US).

(74) Agent: LUCAS, Brian, Ronald; Lucas & Co., 135 Westhall Road, Warlingham, Surrey CR6 9HJ (GB).

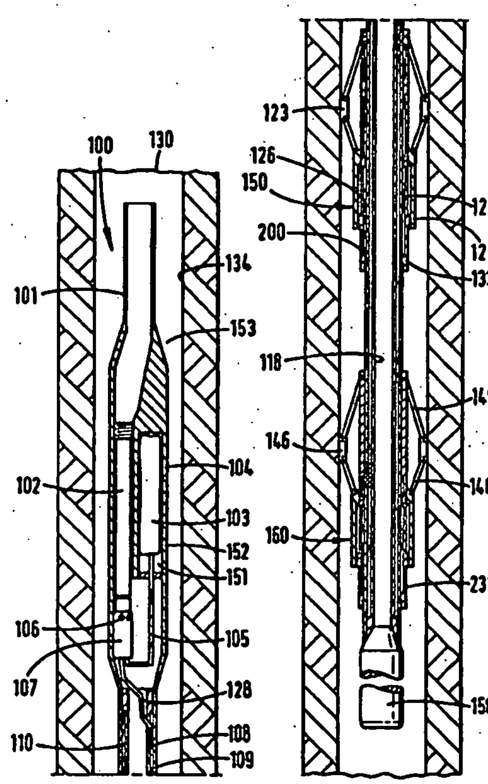
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

**Published**
*With international search report.*
*With amended claims.*

(54) Title: WELLBORE TRACTOR

(57) Abstract

A wellbore tractor system (100, 600, 300) comprising at least one slip unit (123, 634, 311, 413) for alternately and releasably anchoring the system within a wellbore or within a tubular member, the system having a component (101, 651, 327, 418) intended to be moved continuously or stepwise along the axis of the wellbore. When the system has two slip units, they may be powered alternately and in relation to each other so that the system provides continuous motion. Each slip unit is alternately clamped to the wellbore wall and released for longitudinal movement with the axially-movable system component. The units are spaced apart from each other, and the component being moved, to which a payload (158, 651, 324) may be connected, is driven axially relatively to the clamped unit.



*FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AL | Albania | ES | Spain | LS | Lesotho | SI | Slovenia |
| AM | Armenia | FI | Finland | LT | Lithuania | SK | Slovakia |
| AT | Austria | FR | France | LU | Luxembourg | SN | Senegal |
| AU | Australia | GA | Gabon | LV | Latvia | SZ | Swaziland |
| AZ | Azerbaijan | GB | United Kingdom | MC | Monaco | TD | Chad |
| BA | Bosnia and Herzegovina | GE | Georgia | MD | Republic of Moldova | TG | Togo |
| BB | Barbados | GH | Ghana | MG | Madagascar | TJ | Tajikistan |
| BE | Belgium | GN | Guinea | MK | The former Yugoslav Republic of Macedonia | TM | Turkmenistan |
| BF | Burkina Faso | GR | Greece | | | TR | Turkey |
| BG | Bulgaria | HU | Hungary | ML | Mali | TT | Trinidad and Tobago |
| BJ | Benin | IE | Ireland | MN | Mongolia | UA | Ukraine |
| BR | Brazil | IL | Israel | MR | Mauritania | UG | Uganda |
| BY | Belarus | IS | Iceland | MW | Malawi | US | United States of America |
| CA | Canada | IT | Italy | MX | Mexico | UZ | Uzbekistan |
| CF | Central African Republic | JP | Japan | NE | Niger | VN | Viet Nam |
| CG | Congo | KE | Kenya | NL | Netherlands | YU | Yugoslavia |
| CH | Switzerland | KG | Kyrgyzstan | NO | Norway | ZW | Zimbabwe |
| CI | Côte d'Ivoire | KP | Democratic People's Republic of Korea | NZ | New Zealand | | |
| CM | Cameroon | | | PL | Poland | | |
| CN | China | KR | Republic of Korea | PT | Portugal | | |
| CU | Cuba | KZ | Kazakstan | RO | Romania | | |
| CZ | Czech Republic | LC | Saint Lucia | RU | Russian Federation | | |
| DE | Germany | LI | Liechtenstein | SD | Sudan | | |
| DK | Denmark | LK | Sri Lanka | SE | Sweden | | |
| EE | Estonia | LR | Liberia | SG | Singapore | | |

# WELLBORE TRACTOR

This invention relates to wellbore tractors and, in one particular aspect, to a tractor system useful in a non-vertical wellbore to move continuously a tubular string, a wireline, a cable, or coiled tubing.

In vertical wellbores and semi-vertical wellbores which are not highly deviated, wirelines, cable, coiled tubing, tubular strings and tools introduced into the wellbore move down into the wellbore by the force of gravity.

Cable or wireline reaches a deviation threshold (e.g. for certain systems a deviation of about 70° from the vertical, e.g. wireline systems) at which gravity no longer provides the necessary force and resulting tension to move the cable or wireline down and through a wellbore.

To a certain extent, tubular strings and coiled tubing can be pushed through a deviated wellbore, even part of a horizontally or upwardly-directed wellbore; but there is a limit to the length of coiled tubing that can be pushed in this manner. When compressive loads in a tubular string become large enough, the tubular string forms a helical jam in the wellbore (cased or uncased), and further insertion movement is prevented. This is known as "helical lockup."

The present invention relates to a continuous, or nearly-continuous motion, wellbore tractor system which has at least one slip unit (and in certain embodiments two slip units) with retractable slips for engaging an interior wall of casing or of a wellbore, and at least one movement unit for moving an item such as, but not limited to, a tubular string, cable, wireline, or coiled tubing through a wellbore. In one aspect, while the slip unit or slip units are involved in engaging and disengaging from a wellbore, the movement unit(s) move

the item. In one aspect of such a system, with two slip units and two movement units, power strokes of the movement units overlap, so that there is no interruption in the motion of the item.

It is, therefore, an object of the present invention to provide wellbore tractor devices and methods of their use.

Accordingly, the present invention provides a wellbore tractor system which is as claimed in the appended claims.

In one embodiment the present invention discloses a wellbore tractor system for moving an item through a wellbore, the wellbore extending from earth surface to an underground location, the system having a body connected to the item, first setting means on the body for selectively and releasably anchoring the system in a wellbore, first movement means on the body for moving the body and the item, the first movement means having a first power stroke. The wellbore tractor has second setting means for selectively and releasably anchoring the system in the wellbore, the second setting means being spaced apart from the first setting means, and second movement means on the body providing a second power stroke for moving the body and the item, the second movement means being spaced apart from the first movement means. In this a wellbore tractor system the first power stroke temporally overlaps the second power stroke, so that the item is moved continuously.

The item being moved into the wellbore may be a tubular string of interconnected tubular members or a wireline. The wellbore tractor system of this invention may comprise first setting means including a selectively-movable first sleeve, and first slip means pivotably connected to the first sleeve for engaging an interior wall of the wellbore so that, upon movement of the first

sleeve in a first direction, the first slip means is moved into engagement with the interior wall and, upon movement of the first sleeve in a second direction the first slip means is moved out of engagement with the interior wall. It may also comprise hydraulic apparatus for moving the selectively-movable first sleeve, the hydraulic apparatus being powered by fluid under pressure pumped into the hydraulic apparatus from the earth's surface through the item being moved. The wellbore tractor system may comprise a selectively-movable second sleeve, and second slip means pivotably connected to the second sleeve for engaging an interior wall of the wellbore so that, upon movement of the second sleeve in a first direction, the second slip means is moved into engagement with the interior wall and, upon movement of the second sleeve in a second direction, the second slip means is moved out of engagement with the interior wall.

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1A is a side view in cross-section of a wellbore tractor system according to the present invention;

Fig. 1B is an enlargement of a portion of the system of Fig. 1A;

Fig. 1C1 and 1C2 is an enlargement of a portion of the system of Fig. 1A, and includes a schematic representation of an hydraulic circuit of the system;

Fig. 2A is a side view in cross-section of a second embodiment of the present invention;

Fig. 2B is an enlarged view of part of the system of Fig. 2A;

Figs. 3A - 3E illustrate a sequence of operations of the system of Fig. 2;

Fig. 4 is a side view in cross-section of a third embodiment of the present invention;

Fig. 5 is a side view in cross-section of a fourth embodiment of the present invention; and

Figs. 6A - 6D illustrate a sequence of operation of the system of Fig. 5.

As shown in Figs. 1A - 1C, a wellbore tractor system 100 according to the present invention has two tractor units, an upper unit 150 and a lower unit 160. The upper half 150 has a mud motor 102 in fluid communication with a wellbore tubing string 101 such as is typically interconnected with a wellbore mud motor. An inflatable hydraulic fluid reservoir bladder 103 is disposed in a chamber 151 in a housing 152. The mud motor 102 is powered by pressurized fluid selectively supplied through the tubing 101, into the housing 152, to the mud motor 102. Fluid exhausts from the mud motor 102 through ports 106 which are in fluid communication with an internal bore 118 through the system 100.

The mud motor 102 powers a pump 107 which pumps fluid under pressure from the bladder 103 in a line 105 and then in a line 128 through an annulus 108 to the tractor units 150 and 160. The annulus 108 is between an inner housing 110 which is secured to a middle housing 109, both of which are secured to the housing 152.

The tractor units advance the middle housing 109 (and hence the tubing string 101) by pushing against shoulders projecting outwardly from the middle housing 109, an upper shoulder 189 in the upper unit 150 and a lower shoulder 190 in the lower unit 160. Hydraulic circuit piping and other elements interconnecting the pump 107 and various tractor unit control valves and ports are located within the annulus 108. By way of a port 104, the pressure of fluid in an annulus 153 between an inner wall 134 of a wellbore 130 and an outer wall of the mud motor housing 152 is applied to the bladder 103. In the hydraulic circuit shown in Figs. 1B, 1C1 and 1C2, pump 107 pumps fluid under pressure to a control valve 161 and to a control valve 125. The control valve 161 controls the lower unit 160, and the control valve 125 and a second control valve 126 control the upper unit 150.

A valve member 114 disposed around the middle housing 109 has a body 154 with ribs 155, 156, 157 which define a plurality of fluid communication chambers 170, 171, 172, and 173. A sleeve 133 disposed around the middle housing 109 is movable to move the valve member 114 so that various ports are in fluid communication via the communication chambers 170-173. These ports include ports 111, 112, 113, 115, 116 and 117.

Pivotably secured to the outer housing 127 is a first slip arm 131, which is also pivotably secured at its other end to a slip 123. A second slip arm 132 has a first end pivotably secured to the slip 123, and a

second end pivotably secured to the sleeve 133. As the outer housing 127 moves up with respect to the sleeve 133 and with respect to the middle housing 109, the slip arms 131, 132 pivot to move the slip 123 of the upper unit 150 outwardly to contact and engage the inner wall 134 of a wellbore 130.

The upper unit 150 has an outer housing 127 which is movable with respect to the valve member 114 and the middle housing 109. The lower unit 160 has a similar outer housing 147, slip arms 148 and 149, and slip 146 which operate in a similar fashion.

The sleeve 133 has an actitivating ring 122 having a shoulder 197 which upon contact moves a pivot arm 121 of the valve member 114, thereby moving the valve member 114. A spring 120 biases the pivot arm 121, and hence the valve member 114, initially downwardly. An abutment surface 200 on the interior of the sleeves 133 is movable to contact valve stems 144 and 178 of the control valves 125 and 126 respectively to move and operate these control valves. O-rings 201 in corresponding recesses seal interfaces between various elements.

The control valve 125 is disposed in a chamber in the upper shoulder 189 of the middle housing 109 and has a valve member 177 which is connected to the valve stem 178 and is movable to permit fluid flow between ports 174 and 175 or between ports 175 and 176. The control valve 125 controls the fluid flow into a retract chamber 182 or a power chamber 183 of the upper unit 150.

The port 174 is in fluid communication with a flow line 192 to power chamber 183. The port 175 is in fluid communication with a flow line 139 which is in fluid communication with pump 107. The port 176 is in fluid communication with a flow line 191 which is connected to a retract chamber 182.

The control valve 126 is diametrically opposed to

the control valve 125 and works simultaneously in tandem with it. The control valve 126 is also disposed in a chamber in the upper shoulder 189 of the middle housing 109 and has a valve member 140 which is connected to the valve stem 144 and is movable to permit fluid flow between ports 141 and 142 or between ports 142 and 143. The control valve 126 controls the flow of fluid from the retract chamber 182 or from the power chamber 183 of the upper unit 150. The port 143 is in fluid communication with a flow line 167 which is connected to the power chamber 183. The port 142 is in fluid communication with flow line 135 which leads back to bladder 103. The port 141 is in fluid communication with a flow line 166 which is connected to the retract chamber 182.

In a typical cycle of operation of the system 100, the system 100 connected to a tubular string 101 is introduced into the wellbore 130 and located at a desired location therein, e.g. by the force of gravity on the system 100. At that location, motive fluid under pressure is supplied down through the tubular string 101 to the mud motor 102. The mud motor 102 drives the pump 107 which in turn pumps fluid under pressure from the bladder 103, through the line 119, into the annular space 108 for provision to the various valves that control the tractor units 150 and 160.

The pump 107 pumps hydraulic fluid under pressure into a line 199, to a line 138, to the port 112 and to line 139 to the port 175. With the valve member 114 in the position shown in Fig. 1C, fluid flows from the port 112, into the chamber 173, to the port 111, to a line 194, and down to the lower unit 160. The fluid flows into a power chamber 181 of the lower unit 160 and flows from the power chamber 181, through a port 187, into a chamber 186 setting the slip 146 of the lower unit. The fluid in the chamber 181 then pushes on the lower shoul-

der 190 and moves the middle housing 109 down. the fluid in chamber 180 escapes via line 195 through port 115 in valve member 114 and through port 116 to bladder 103. The sleeve 133 of the upper unit 150 simultaneously moves in a similar fashion by fluid entering port 175 via line 139 into valve 161 which directs fluid into upper power chamber 183 via line 192. The fluid in chamber 182 escapes via line 166 into valve 140 and to bladder 103.

The system 100/tubing 101 is moving downwardly in the wellbore at this point in the cycle.

As the sleeve 133 moves upwardly, the shoulder 197 of the activating ring 122 contacts and then pushes on the pivot arm 121, compressing the spring 120, and moving the valve member 114 upwardly (as viewed in Fig. 1C).

As the pivot arm 121 is moves toward a notch 119, the valve member 114 move upwardly and fluid flow is stopped between the ports 111 and 112, cutting off the flow of fluid to the power chamber 181 of the lower unit 160. At this point the power stroke of the lower unit 160 ceases. While the activating ring 122 moves upwardly over the pivot arm 121 in the notch 119, the valve member 114 is prevented from moving downwardly, and fluid flows through the port 112, through a chamber 172, through a port 113, to a line 195, to a retract chamber 180 of the lower unit 160, and retraction commencing the retraction cycle..

The size, length, disposition, and configuration of the activating ring 122 determine the length of time that fluid flows from the power chamber 181 of the lower unit 160. During this period, there is no fluid communication between the ports 111 and 112. As the retract chamber 180 begins to fill with fluid under pressure and move the sleeve 233 downwardly, fluid in the power

chamber 181 escapes through the line 194, to a line 137, to the port 117, to the chamber 170, to the port 116, to the line 193, to the line 136, and back to the bladder 103.

Once the activating ring 122 has moved upwardly beyond the notch 119, the pivot arm 121 is freed and is pivoted outwardly by the spring 120, and the valve member 114 is freed to move downwardly, again positioning the chamber 173 so that fluid communication between the ports 111 and 112 occurs. Fluid flows into the lower power chamber 181, and a new power stroke of the lower unit 160 commences. At every moment in the cycle, power is provided to move the tubular string 101 by the upper unit 150, by the lower unit 160, or by both.

The control valves 125 and 126 control the flow of fluid under pressure to and from the upper unit 150. When the sleeve 133 has moved upwardly to a sufficient extent, the abutment surface 200 contacts the valve stems 144 and 178. Subsequent movement of the valve members 140 and 177 results in fluid escaping from the upper power chamber 183 to bladder 103 via line 167 and valve 126 and fluid into the upper retract chamber 182 via line 191 and valve 125, shifting the upper unit 150 from a power stroke to a retraction stroke.

When the retraction stroke of the upper unit 150 begins, the power stroke of the lower unit 160 is already in progress (due to the timed and controlled introduction of fluid into the lower power chamber 181 as described above). When the retract stroke of the lower power unit 160 begins, the power stroke of the upper unit 150 is already in progress. Thus power is provided for the continuous movement of the tubular string 101.

When the sleeve 133 of the upper unit 150 moves back downwardly, the valve stems 144 and 178 contact an

upper abutment surface 203 which shifts the valve members 140 and 177 back to their initial positions (e.g. as in Fig. 1C) and a power stroke of the upper unit 150 commences.

A payload 158 such as logging tools, perforating guns, sand clean-out equipment or any item run on the end of coiled tubing or on the end of a wireline) is connected to the bottom of the middle housing 109.

Another embodiment of the invention is shown in Fig. 4, and is used to move a tubular string 302. Of course this system may be used to move pipe, cable, casing, or coiled tubing. A payload 324 is connected to a lower end 328 of a hollow mandrel 327. An upper end 329 of the mandrel 327 is connected to the tubing 302, and the bore 337 of the mandrel 327 is in fluid communication with a flow bore 338 through the tubing 302.

Fluid at relatively high pressure is pumped down the tubing 302 into the mandrel 327, such as from a surface mud pump which pumps high-pressure liquid, which enters the mandrel 327 and exits it through exhaust ports 323 near the lower end 328. Preferably the liquid is at a sufficiently high pressure that the fluid pressure within the mandrel 327 is higher than the pressure of fluid in a wellbore 334 through which the system 300 extends.

The high pressure liquid enters an expansion chamber 307 through a port 308. The expansion chamber 307 is defined by an exterior surface of the mandrel 327, an interior surface of a slip housing 314, and a mandrel seal 309. The fluid also enters a slip set chamber 304 through a port 305 which is in fluid communication with the expansion chamber 307. The slip set chamber 304 is defined by an outer surface of the slip housing 314, and an inner surface of an upper housing 303.

The increased pressure in the slip set chamber 304

moves the upper housing 303 against a spring 306 and toward a bottom housing 321. The spring 306 initially abuts an inner shoulder 335 on the upper housing 303 and a lower outer shoulder 336 of the slip set housing 314, and urges these two members apart. This movement of the upper housing 303 (down in a vertical wellbore, laterally in a horizontal wellbore, at a diagonal in an inclined wellbore) toward the lower housing 321 results in the setting of slips 311 against an inner wall 334 of the wellbore 330, setting the slips and centering the system 300 in the wellbore 330.

Each slip 311 has one end pivotably connected to a lower slip arm 312 which has a lower end pivotably connected to the slip housing 314, and its other end pivotably connected to an upper slip arm 310 which has its upper end pivotably connected to the upper housing 303. Setting of the slips 311 secures the upper housing 303 and the bottom housing 321 in place in the wellbore 330.

The high-pressure liquid pushes against the seal 309, expanding the expansion chamber 307 and pushing the mandrel 327 (downwardly in Fig. 4), which results in longitudinal movement of the tubing 302. This also decreases the volume of a hydrostatic chamber 325 the liquid escaping post the stop 315 into the wellbore 330, while increasing the volume of a sub-hydrostatic chamber 326. The hydrostatic chamber 325 is defined by an outer surface of the mandrel 327 and an inner surface of sliphousing 314. The sub-hydrostatic chamber 326 is similarly defined. Movement of the mandrel 327 ceases when the seal 309 abuts a stop 315 on the inner surface of the slip housing 314. When the tubing string ceases its motion, the pumping of fluid into the tubing is stopped and then the pressure in the expansion chamber 307 and in the slip set chamber 304 equalize with the

pressure in the wellbore 330. This allows the spring 306 to move the upper housing 303 away from the bottom housing 321, which results in the disengagement of the slips 311 from the wall 334 of the wellbore 330.

Fluid pressure in the sub-hydrostatic chamber 326 is significantly less than (such as 5000 psi (34MPa)to 6000psi (41MPa) the hydrostatic pressure ) of fluid in the wellbore 330, in the expansion and slip set chambers, and in a buffer chamber 319 below the sub-hydrostatic chamber 326. This pressure differential causes the sub-hydrostatic chamber 326 to contract along with the expansion chamber 307 as the hydrostatic chamber 325 expands. A spring 341 acts to dissipate the force of undesired impacts on the system and/or on the payload 324. As a result of these chamber expansions and contractions, the upper housing 303 and the bottom housing 321 (with the slips disengaged from the wellbore) move down with respect to the mandrel 327 until the spring 341 is completely compressed.

When the system 300 has moved, the surface mud pump is again activated to set the slips and move the mandrel to advance the tubing 302. A system such as the system 300 may be activated and deactivated by an operator at the surface cycling a pump to pump fluid down to the system. In one aspect the system will be 'on' for intervals of about 30 s, and 'off' for intervals of about 30 s. In some embodiments of this invention, it is possible to cycle the system at intervals as long as 3 minutes or as short as 30 s. It is within the scope of this invention to use two or more tractor systems connected together so that the power strokes of the systems overlap, providing continuous motion of the payload.

Fig. 5 shows a wellbore tractor system 400 of the invention which provides near-continuous motion to move

an item through a wellbore 480.

The system 400 has a mandrel 450 with two tractor elements, a lower (or front) tractor unit 422, and an upper (or rear) tractor unit 413. The mandrel 450 is connected at one end to an item or string to be moved through a wellbore.

The system 400 has two hydraulic circuits, a power-retract circuit for the two tractor units (including lines 463, 468 and 418), and a control circuit (including lines 464, 465, 467, 472, 407, 460 and 469 and valves 405, 406, 410 and 420).

Fluid for controlling the upper tractor unit flows to and from a rear pilot control valve 405, and fluid for controlling the lower tractor unit flows to and from a front pilot control valve 420. A pump 430 for the system may be driven by a downhole motor or it may be electrically powered and run on a cable. The pump 430 pumps fluid to and from a sump 431 and/or a sump 432.

The upper tractor unit 413 has an arm mount 481 to which is pivotably connected an end of a first arm 482. The other end of the first arm 482 is pivotably connected to slip 483. The other end of the slip 483 is pivotably connected to an arm mount 485. A slip set piston 419 coacts with the arm mount 481. A seal 486 (such as an O-ring seal) seals the mandrel/slip set piston interface at one end of the slip-set piston 419. The other end of the slip-set piston 419 wraps over the outer end of the arm mount 481. An operating piston 417 is movably disposed between the slip-set piston 419 and the mandrel 450. A port 416 is located between an end of the operating piston 417 and the arm mount 485. A seal 487 seals the operating piston/mandrel interfaces. A seal 488 seals the arm mount/mandrel interface and the arm mount/slip-set piston interface. The mandrel has exterior shoulders 490, 491, 492 and 493.

A spring 494 urges a rear pilot control valve 405 away from the shoulder 490. A spring 495 urges a front pilot control valve 420 away from the shoulder 492. A spring 496 urges the arm mounts 481 and 485 apart. Seals 497 seal the rear-pilot-valve/mandrel interface. Seals 498 seal the front-pilot-valve/mandrel interface.

The lower tractor unit 422 has an arm mount 501 to which is pivotably secured one end of an arm 502. The other end of the arm 502 is pivotably secured to one end of a slip 503. The other end of the slip 503 is pivotably secured to one end of an arm 504. The other end of the arm 504 is pivotably secured to an arm mount 505. One end of a slip-set piston 424 wraps over the arm mount 505 and the other end of the slip-set piston moves along the mandrel 450. A seal 506 seals the slip-set-piston/mandrel interface at one end of the slip-set piston 424. An operating piston 426 is movably disposed between the slip-set piston 424 and the mandrel 450. A seal 507 seals the shoulder 493/operating-piston interface. A seal 508 seals the operating-piston/mandrel interface. A seal 509 seals the arm-mount/mandrel interface and the arm-mount/slip-set-piston interface.

As shown in Figs. 5 and 6B, fluid under pressure through a line 468 enters an upper power chamber 437. A portion of this fluid passes through a port 416, between the operating piston 417 and the slip-set piston 419, to a chamber 439. As the chamber 439 expands, the upper end of the slip-set piston 419 pushes the arm 482 and related apparatus so that the slips of the lower tractor unit 413 are moved out to engage the wellbore wall. Simultaneously fluid under pressure in the upper power chamber 437 acts on a shoulder 491, driving the system 400 (to the right in Fig. 5) and the item or string attached to it further into the wellbore. Fluid in the retraction chamber 447 escapes through line 471.

Simultaneously fluid under pressure in a line 418 from a valve 406 enters a chamber 436 to retract the slips of the lower tractor unit 422. In Fig. 6B the upper tractor unit's power stroke is nearly finished, and the retract stroke of the lower tractor unit is complete.

The arm mount 481 pushes valve 405 so as to link control lines 408 and 407 which shifts valve 410 (see Fig. 6C). A bleed valve 411 provides sufficient flow restriction in the pilot control port to allow the valve 410 to shift. Hence fluid under pressure is directed through a line 468 from retract chamber 447 of the upper tractor unit 413 to sump 432 and from pump 430 to power chamber 466. Retraction of the slips of the upper tractor unit 413 commences due to spring 496 forcing arm mount 481 and arm mounted 485 apart and hence fluid from chamber 439 into the low pressure sump 432. The chamber 466 of the lower tractor unit 422 begins filling, and the power stroke of the lower tractor unit 422 commences. At this time the lower tractor unit's retract chamber 436 is in fluid communication with a sump or reservoir 432 via line 418. The sumps 431 and 432 are indicated in two locations schematically, although only one sump may be used.

As shown in Fig. 6B, fluid pressure in the power chamber 437 of the upper tractor unit is greater than that in the retract chamber 436 of the lower tractor unit, i.e., so the power chamber receives fluid at a sufficiently-high pressure to move the mandrel 450, while a pressure-relief valve 406 controls pressure in the various lines and ensures that pressure in the retract chamber is sufficient for retraction, but not greater than the pressure in the power chamber of the upper tractor unit.

Preferably the dwell time between power strokes of the two tractor units, that is, the time required for

the valve 410 to switch power fluid from one tractor's power chamber to the other chamber's power chamber, is at most 5% of the cycle time, more preferably at most 2%, and most preferably 1%.

As the system 400 moves the mandrel 450, the slip-set piston 501 compresses the spring 495 and moves the pilot valve 420 so that fluid communication commences between lines 500 and 469. This permits fluid to flow through the line 469 to operate valve 410, thereby shifting the lower tractor unit from a power stroke to a retract stroke, and shifting the upper tractor unit from a retract stroke to a power stroke.

Figs. 6A - 6D show the sequence of operation of the system 400. Fig. 6A shows the system as in Fig. 5 for running a payload into a wellbore or tubular. In Fig. 6B, the upper tractor unit 413 is in its power stroke, and the lower tractor unit 422 is in its retract stroke. In Fig. 6C, the upper tractor unit 413 is in its retract stroke and the power stroke of the lower tractor unit 422 has begun. Fig. 6D is like Fig. 6B, but in Fig. 6D the upper unit has just reached the end of a power stroke and is switching to a retract stroke, while the lower unit has just ended its retract stroke and is starting to set its slips. Hydraulic fluid pressure in all chambers of the tractor elements is equalized (to stop the tractor system with the slips on both units retracted, such as in order to remove the tractor system from the wellbore) with the pressure of fluid in the wellbore 480, by means of the bleed valves 411 and 412, through which fluid bleeds back to the sump 432. Arrows on flow lines indicate flow direction.

In Fig. 6B the upper tractor unit 413 has been activated so that its slip 483 is moved to engage the wellbore wall 484. The pump 430 provides hydraulic fluid under pressure to the power chamber 437 and the

rear operating piston 417 through a line 415. The pilot-operated directional valve 410 controls flow through the line 415. The valve 410 is detented to provide a toggle action between two control positions and, in the absence of pilot pressure through a line 472 or a line 469, remains in the last position to which it is piloted. For start up, the valve 410 can be in either position, since fluid will be directed to a power piston of one of the tractor units, and either lines indicate flow direction.

Fluid pressure in the power chamber 437 higher than the fluid pressure in the retract chamber 447 forces the mandrel 450 to traverse down the borehole (see Fig. 6B). Fluid exhausted from the retract chamber 447 is fed through a reducing/relieving valve 406 back to the sump 432.

This cyclical motion is repeated as long as the pump 430 is producing fluid under pressure, causing the system to "walk" through or down the borehole. When the pump 436 is stopped, the power lines 468 and 463 to both power chambers bleed back to sump pressure. Spring loading of the slippers causes them to collapse back to the initial state, allowing the system to be retrieved from the hole.

There are three or four such units 413, 422 spaced at 120° or 90° around the mandrel so that the mandrel stays substantially central in the borehole.

Figs. 2 and 3A - 3E show a system 600 according to the present invention.

The system 600 has a lower tractor unit 610, an upper tractor unit 620, and a central mandrel 653. The central mandrel 653 has in it a metre helical passage 631, the power thread, at one pitch (e.g. about six complete turns per metre) and a second helical passage 632, the retract thread, at another pitch (e.g. about

three complete turns per metre). A downhole motor 652 is connected to the central mandrel 653 and is selectively powered from the surface to rotate the central mandrel 653. There are two spaced-apart sets of oppositely-handed helical passages 631, 632.

The system 600 provides continuous motion since, due to the difference in pitch of the two passages 631 and 632, the power stroke of each tractor unit during which the system moves into the wellbore, is longer in length than the return stroke. The return stroke is the part of the power cycle of a tractor unit in which the tractor unit is not advancing the system along the wellbore, but is being moved with the system while the other tractor unit is anchored against the wellbore's interior.

In a typical cycle of operation of the system 600, motive fluid is pumped down tubing 651 from the surface to power the mud motor 652. This rotates the mud motor, which in turn rotates the central mandrel 653. A passage follower 655 secured to the middle housing 656 engages and rides in the passage (which includes the power thread handed in one direction and the retract thread handed in the other direction) thereby moving a middle housing 656 (upwards in Fig. 2) in relation to an inner housing 657. This movement decreases the size of a power chamber 658, and fluid therein is compressed. This fluid is transmitted through a port 659 to a slip-set chamber 678. Introduction of the fluid into the slip-set chamber 678 expands the chamber, resulting in the movement of an outer housing 660 (upwards in Fig. 2) over the middle housing 656, thereby setting slips 634.

As the slip-setting continues, excess fluid in the slip-set chamber 678 flows through a pressure regulator valve port 663 into a reservoir chamber 662, thus maintaining a constant pressure, slightly above the hydro-

static pressure of fluid in the wellbore annulus and in the slip set chamber 678, keeping the slips 634 set. A compensating piston 664 maintains a constant hydrostatic pressure (pressure level in the annulus between the system's exterior and the wellbore's interior) in the reservoir chamber 662. A retaining collar 665 prevents the compensating piston 664 from moving past the lower end of the middle housing 656 and hydrostatic ports 663 allow hydrostatic pressure from the wellbore to act below the compensating piston 664.

The follower 655 in the passage 631 also pulls the inner housing 657 through the middle housing 656 and through the outer housing 660 through a centralizer 667, thus moving the tubing 651 into the wellbore.

At the end of the power stroke, the follower 655 reaches the end of its passage 631, and shifts into the retract passage 632, reversing its longitudinal movement to begin a retract cycle. During the retract cycle of one tractor unit, the fluid pressure in all the chambers of the unit returns to hydrostatic pressure <u>via</u> ports 659, 663 and 666, allowing disengagement and unsetting of the slips. With the slips of the upper tractor unit disengaged, the middle housing 656 and outer housing 660 are pulled downward relative to the inner housing 657 by the lower tractor unit. At the end of the retract cycle of the upper unit, the follower 655 again enters the power passage and reverses its longitudinal movement to commence another power stroke of the upper unit.

Since both the upper tractor unit 620 and the lower tractor unit 610 operate on the central mandrel 653 with its interconnected power and retract passages, and each unit's power stroke is longer than its retract stroke, the power strokes will always overlap in time, and the system 600 will provide continuous motion. It is always the case that, when one unit is in its retract stroke

the other unit is in part of its power stroke. It is within the purview of this invention for the helical passages and followers to be replaced by a helical screw-thread with appropriate grooved followers.

Figs. 3A - 3E illustrate a typical cycle of the system 600. In Fig. 3A, the power stroke of the upper tractor unit 620 is ending and the retract stroke of the lower tractor unit 610 is ending. In Fig. 3B, the upper tractor unit's slips 634 have been disengaged, and the power stroke of the lower tractor unit 610 is commencing. In Fig. 3C, the retract stroke of the upper tractor unit 620 is nearing an end and the power stroke of the lower tractor unit 610 is on-going. In Fig. 3D, the slips of the upper tractor unit 620 have been set, the power stroke of the upper tractor unit 620 has commenced, the power stroke of the lower tractor unit 610 has ended and its retract stroke is beginning. In Fig. 3E, the power stroke of the upper tractor unit 620 is nearing its end, and the retract stroke of the lower tractor unit 610 is on-going, with the slips of the lower tractor unit 610 disengaged. The lower unit 610 is like the upper unit 620.

A tractor system according to the present invention may be run with a "full-bore" payload that has a path therethrough or thereon for conveying power fluid to the tractor system.

In conclusion, therefore, it is seen that the present invention provides a wellbore tractor system that represents a significant technical advance over known systems.

CLAIMS

1. A wellbore tractor system (100, 600, 300) for moving a component (101, 651, 327, 418) along a wellbore or like passage (134, 334, 484) extending from the surface to an underground location, the system comprising:

a body (109, 656, 314, 421) connected to the component, the body having mounted on it means (123, 634, 311, 413) for selectively anchoring the body to the inner surface of the wellbore in a releasable manner;

means (190, 655, 318, 491) for moving the component longitudinally relative to the anchoring means when set, and

means (122, 632, 341, 496) for moving the anchoring means longitudinally of the component, in the direction of travel thereof, after the anchoring means has been disengaged from the wellbore surface.

2. A system as claimed in Claim 1, powered by an intermittently-driven pump for supplying fluid under pressure to the interior of the component, the fluid being vented into the wellbore, the cyclic and successive anchoring and longitudinal movement phases being effected in accordance with the instantaneous pressure differential between the component interior and the wellbore.

3. A system as claimed in Claim 1, including a second anchoring means (146, 610, 503) mounted on the component at an axially-spaced location, the two anchoring means being adapted to be powered in alternating anchoring and longitudinal movement phases, which phases overlap in time so that movement of the component is substantially continuous.

4. A system as claimed in any preceding claim, in which the or each anchoring means includes an axially-movable sleeve (124, 620, 314, 566) of which axial

movement relative to its support body (109, 656, 329, 491) effects radial movement of its wellbore slipping feet (123, 634, 311, 413).

5. A system as claimed in Claim 4, in which the relative axial movement of the sleeve is effected by hydraulic fluid of which the pressure is controlled, the fluid being supplied to the interior of the component from a surface-mounted pump.

6. A system as claimed in Claim 3, or Claim 3 and any claim dependent therefrom, in which the supply of hydraulic fluid to the anchoring means is controlled by control valves (126, 405, 420) in the form of collars embracing the body and movable axially thereof to interconnect associated hydraulic fluid lines.

7. A system as claimed in Claim 3, or Claim 3 and any claim dependent thereon, in which both anchoring means are powered by the rotary movement of a common mandrel (653) having in it composite helical passages (632, 654) of which the pitches of the oppositely-handed portions are different from each other, each set of passages being engaged by a follower (655) fast with one each of the anchoring means, the followers being engaged in different parts of its respective set of passages, whereby only one anchoring means is fully anchored to the wellbore at any instant, causing rotation of the mandrel to effect longitudinal movement of both the mandrel and the disengaged anchoring means, relative to the engaged anchoring means.

8. A system as claimed in any preceding claim, in which the component of the system is connected to a payload (158, 651, 324) for movement therewith.

9. A method of moving a payload using the system as claimed in any preceding claim.

## AMENDED CLAIMS

[received by the International Bureau on 17 December 1997 (17.12.97); original claim 1 amended; new claims 10 and 11 added; remaining claims unchanged (4 pages)]

1. A wellbore tractor system (100, 600, 300) for moving a component (101, 651, 327, 418) along a wellbore or like passage (134, 334, 484) extending from the surface to an underground location, the system comprising:

a body (109, 656, 314, 421) connected to the component, the body having mounted on it means (123, 634, 311, 413) for selectively anchoring the body to the inner surface of the wellbore in a releasable manner;

means (190, 655, 318, 491) for moving the component longitudinally relative to the anchoring means when set, and

means (122, 632, 341, 496) for moving the anchoring means longitudinally of the component, in the direction of travel thereof, after the anchoring means has been disengaged from the wellbore surface,

characterised in that said means (190, 655, 318, 491) for moving said component longitudinally relative to said anchoring means when set is capable of advancing said component ahead of said anchoring means.

2. A system as claimed in Claim 1, powered by an intermittently-driven pump for supplying fluid under pressure to the interior of the component, the fluid being vented into the wellbore, the cyclic and successive anchoring and longitudinal movement phases being effected in accordance with the instantaneous pressure differential between the component interior and the wellbore.

3. A system as claimed in Claim 1, including a second anchoring means (146, 610, 503) mounted on the component at an axially-spaced location, the two anchoring means being adapted to be powered in alternating anchoring and longitudinal movement phases, which phases overlap in time so that movement of the component is substantially

continuous.

4. A system as claimed in any preceding claim, in which the or each anchoring means includes an axially-movable sleeve (124, 620, 314, 566) of which axial movement relative to its support body (109, 656, 329, 491) effects radial movement of its wellbore slipping feet (123, 634, 311, 413).

5. A system as claimed in Claim 4, in which the relative axial movement of the sleeve is effected by hydraulic fluid of which the pressure is controlled, the fluid being supplied to the interior of the component from a surface-mounted pump.

6. A system as claimed in Claim 3, or Claim 3 and any claim dependent therefrom, in which the supply of hydraulic fluid to the anchoring means is controlled by control valves (126, 405, 420) in the form of collars embracing the body and movable axially thereof to interconnect associated hydraulic fluid lines.

7. A system as claimed in Claim 3, or Claim 3 and any claim dependent thereon, in which both anchoring means are powered by the rotary movement of a common mandrel (653) having in it composite helical passages (632, 654) of which the pitches of the oppositely-handed portions are different from each other, each set of passages being engaged by a follower (655) fast with one each of the anchoring means, the followers being engaged in different parts of its respective set of passages, whereby only one anchoring means is fully anchored to the wellbore at any instant, causing rotation of the mandrel to effect longitudinal movement of both the mandrel and the disengaged anchoring means, relative to the engaged anchoring means.

8. A system as claimed in any preceding claim, in which the component of the system is connected to a payload (158, 651, 324) for movement therewith.

9. A method of moving a payload using the system as claimed in any preceding claim.

10. A wellbore tractor system (100, 600, 300) for moving a component (101, 651, 327, 418) along a wellbore or like passage (134, 334, 484) extending from the surface to an underground location, the system comprising:

a body (109, 656, 314, 421) connected to the component, the body having mounted on it means (123, 634, 311, 413) for selectively anchoring the body to the inner surface of the wellbore in a releasable manner;

means (190, 655, 318, 491) for moving the component longitudinally relative to the anchoring means when set, and

means (122, 632, 341, 496) for moving the anchoring means longitudinally of the component, in the direction of travel thereof, after the anchoring means has been disengaged from the wellbore surface,

characterised by a second anchoring means (146, 610, 503) mountable on the component at an axially-spaced location, the two anchoring means being adapted to be powered in alternating anchoring and longitudinal movement phases, which phases overlap in time so that movement of the component is substantially continuous.

11. A wellbore tractor system (100, 600, 300) for moving a component (101, 651, 327, 418) along a wellbore or like passage (134, 334, 484) extending from the surface to an underground location, the system comprising:

a body (109, 656, 314, 421) connected to the component, the body having mounted on it means (123, 634, 311, 413) for selectively anchoring the body to the inner surface of the wellbore in a releasable manner;

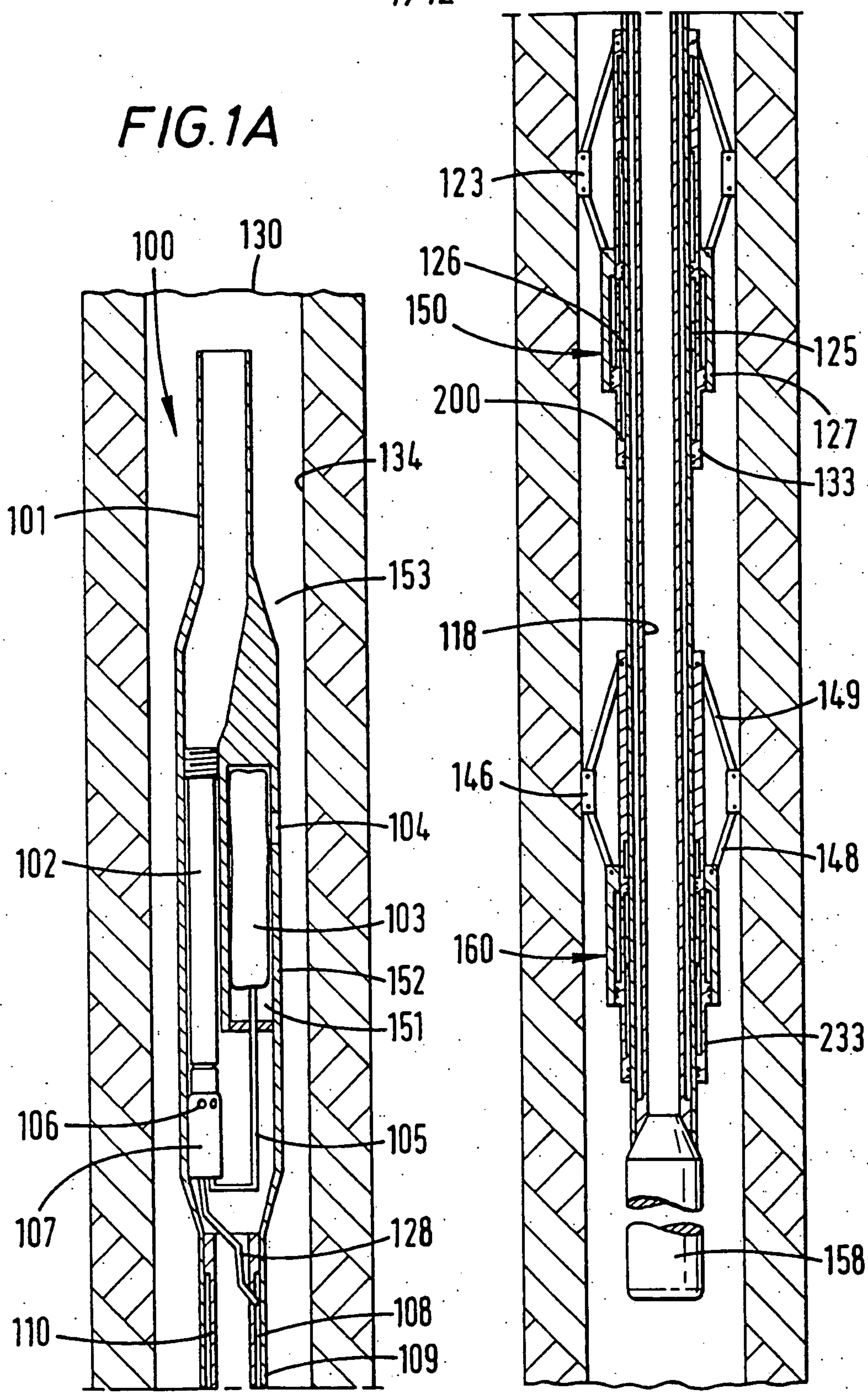
means (190, 655, 318, 491) for moving the component longitudinally relative to the anchoring means when set,

and

means (122, 632, 341, 496) for moving the anchoring means longitudinally of the component, in the direction of travel thereof, after the anchoring means has been disengaged from the wellbore surface,

characterised in that the anchoring means comprises a plurality of wellbore slipping feet (123, 634, 411, 413) pivotally mounted to arms (148, 149, 310, 312, 482, 504), and a sleeve (124, 620, 314, 566) slidably mounted on a support body (109, 656, 329, 491) the arrangement being such that axial movement of said sleeve relative to said support body effects radial movement of said wellbore slipping feet (123, 634, 311, 413).

FIG.1A


100
130
134
101
153
104
102
103
152
151
106
105
107
128
110
108
109
123
126
150
125
200
127
133
118
149
146
148
160
233
158

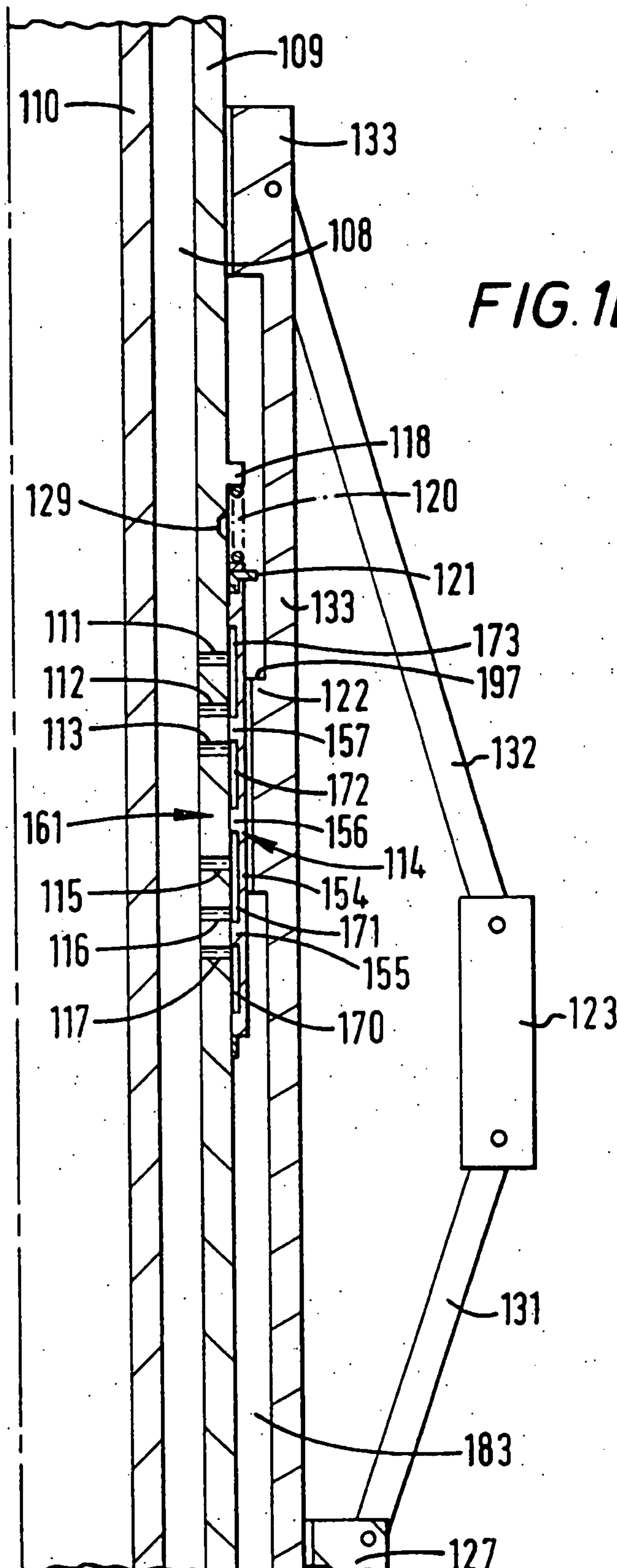
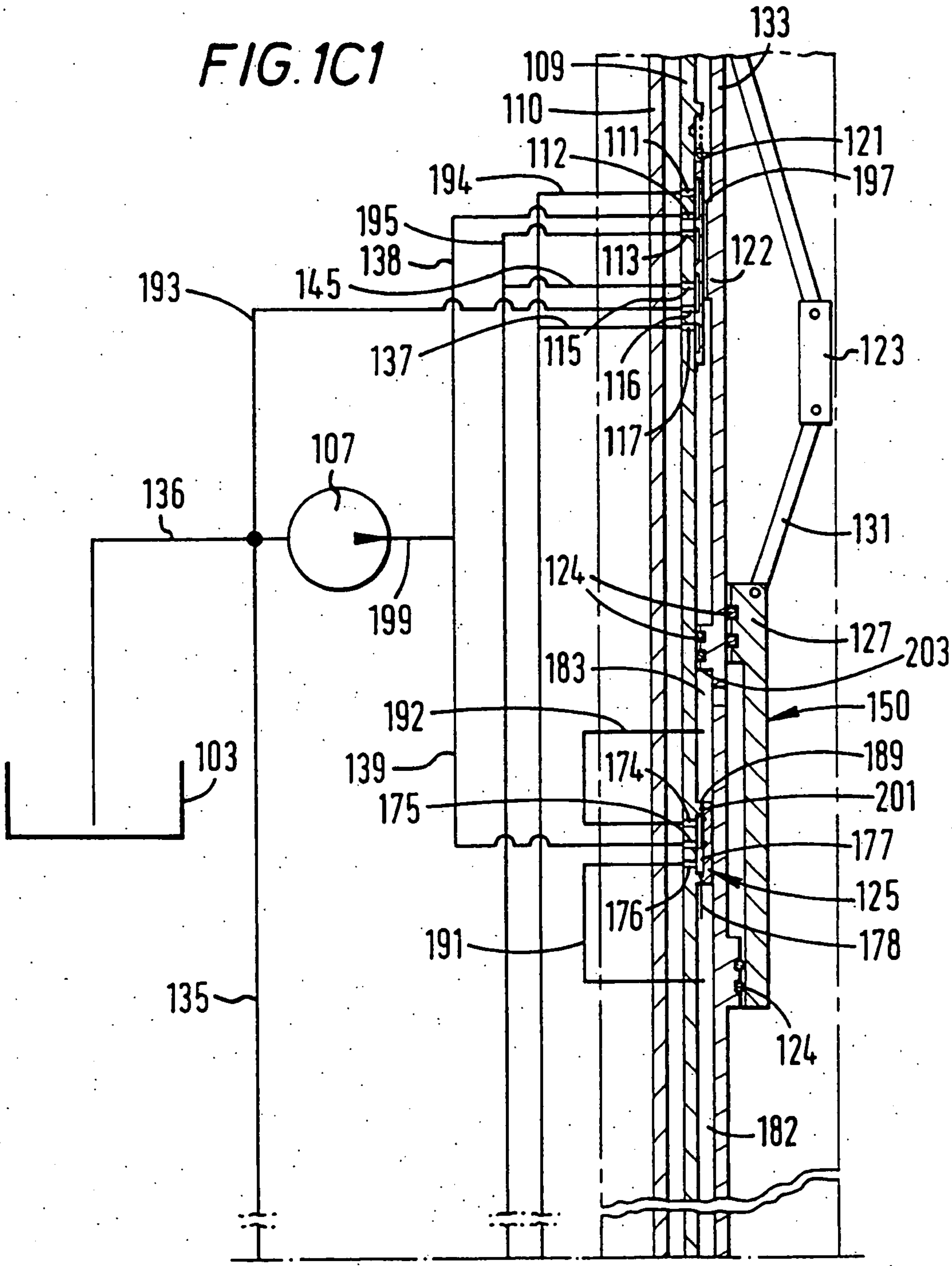

109
110
133
108
118
129
120
121
133
111
173
112
197
122
113
157
172
161
156
114
115
154
171
116
155
117
170
123
132
131
183
127

FIG. 1B

FIG. 1C1


133
109
110
111
121
112
197
194
195
113
122
138
145
193
115
116
123
137
117
107
136
131
199
124
127
203
183
150
192
189
103
174
139
201
175
177
125
176
178
191
135
124
182

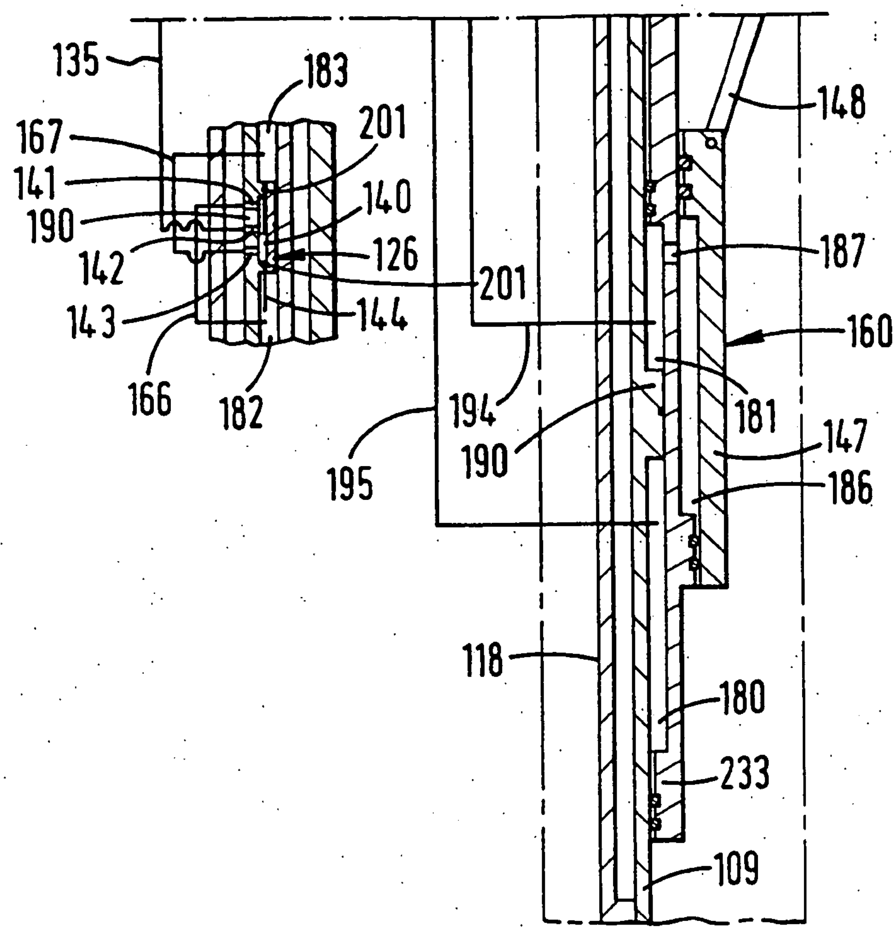

135
183
167
201
141
140
190
126
142
201
143
144
166
182
148
187
160
194
181
195
190
147
186
118
180
233
109

FIG.1C2

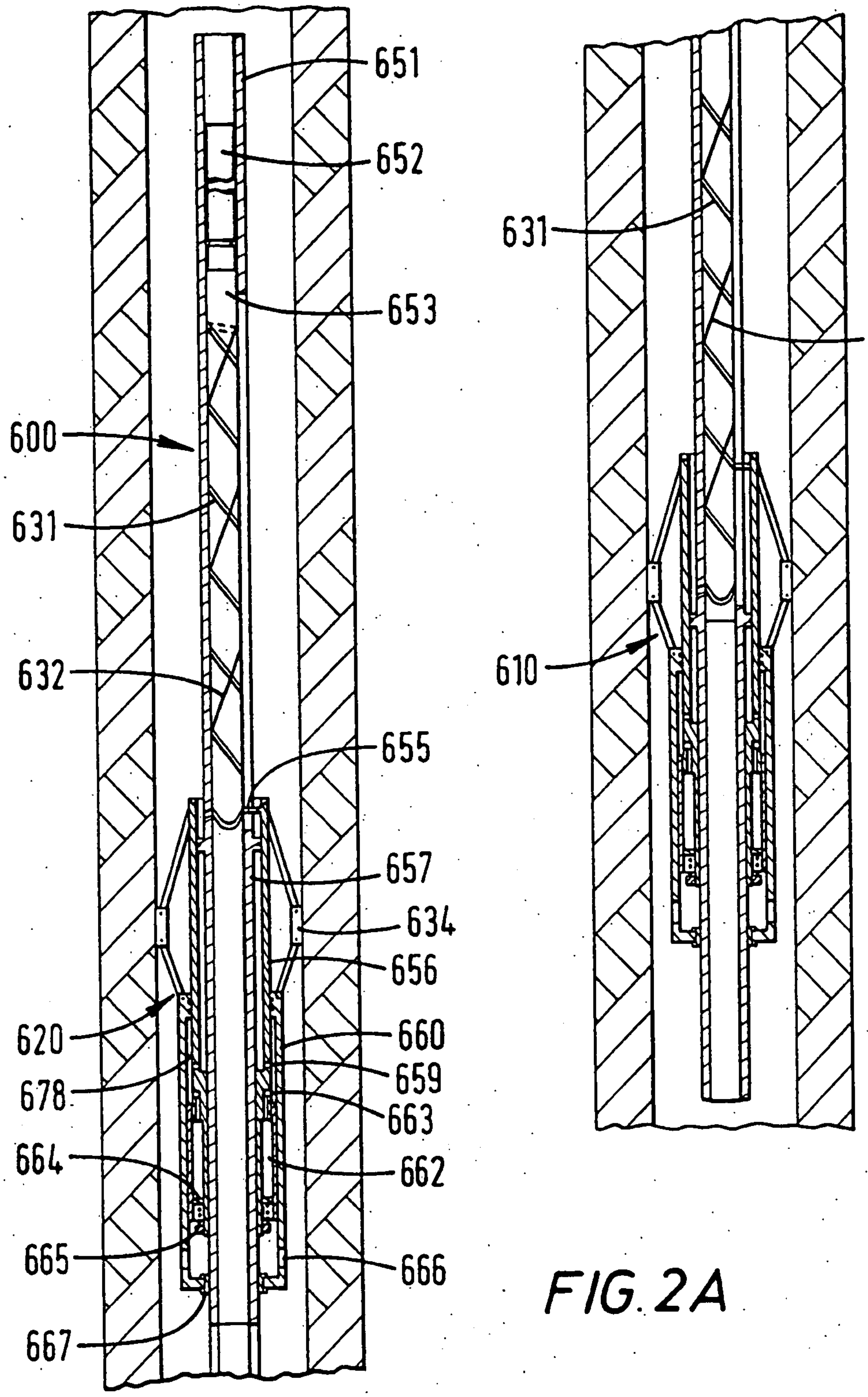

651
652
653
600
631
632
655
657
634
656
620
660
678
659
663
664
662
665
666
667
631
632
610

FIG. 2A

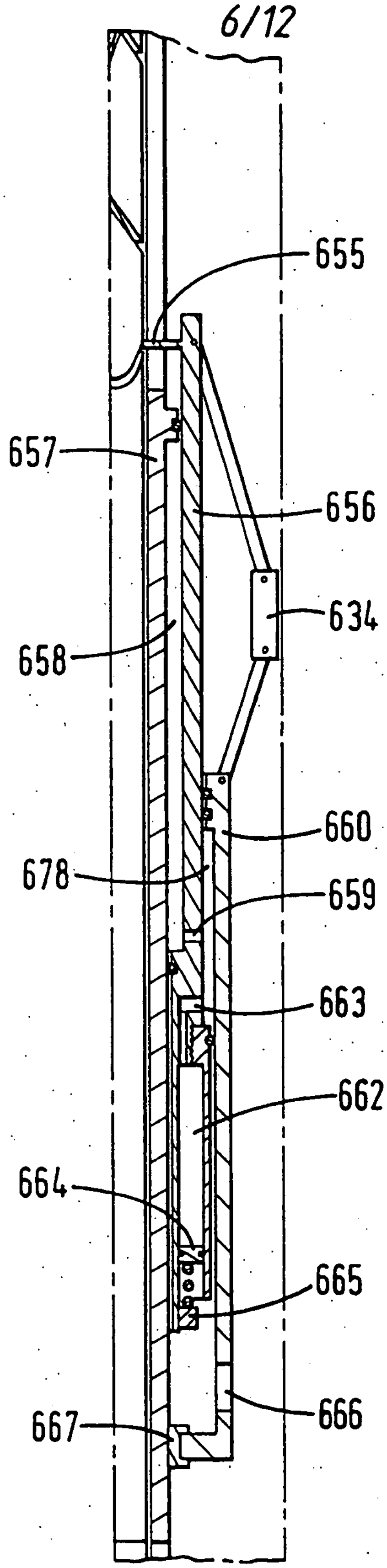



FIG. 2B

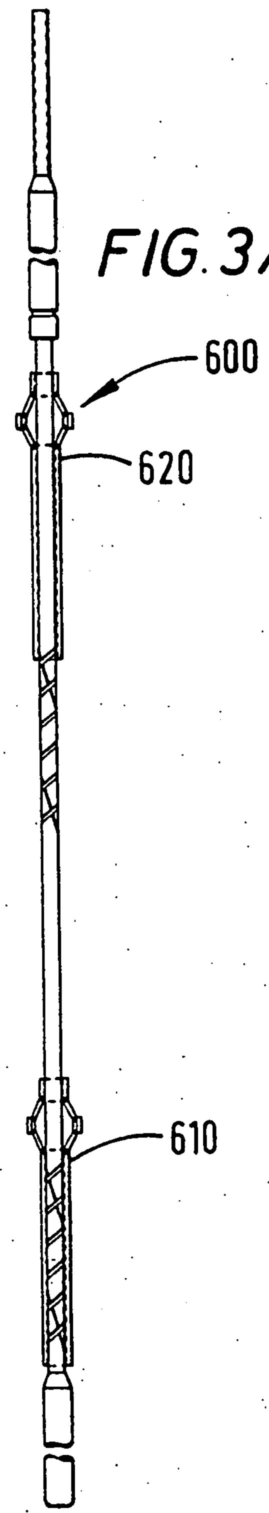



FIG. 3A

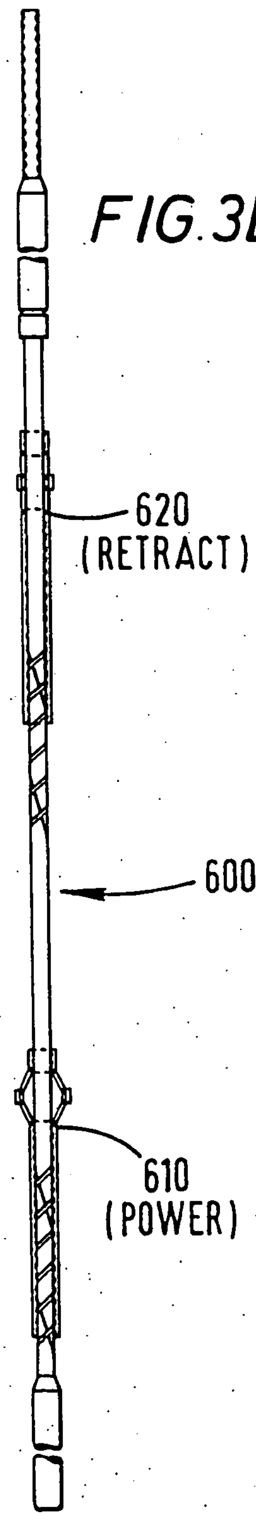



FIG. 3B

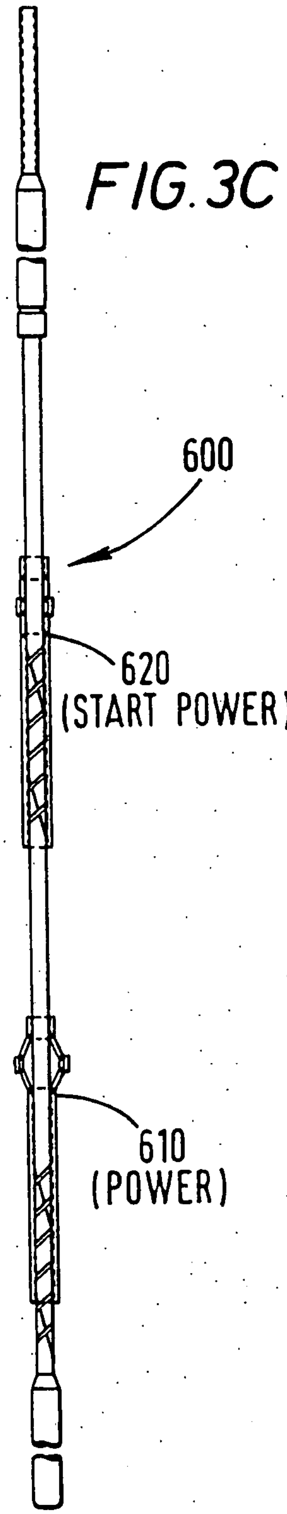



FIG. 3C

FIG. 3D

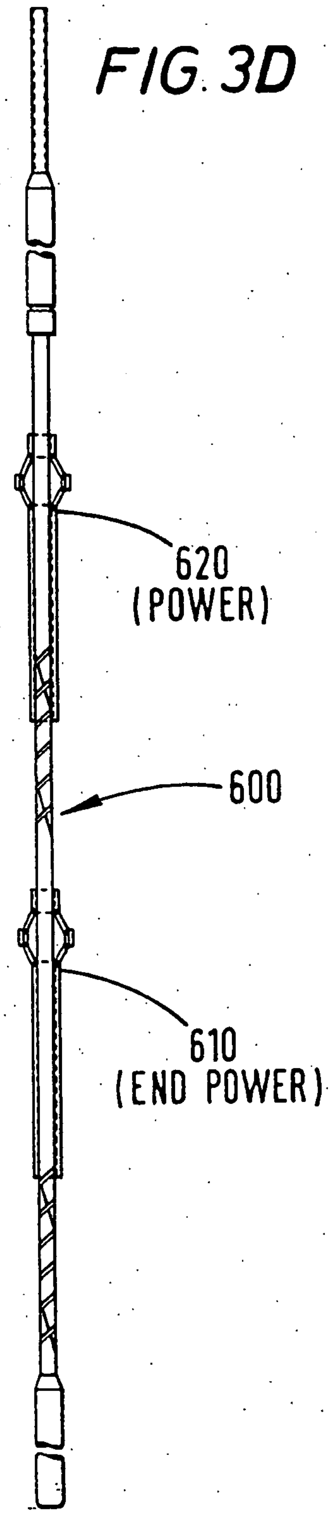



FIG. 3E

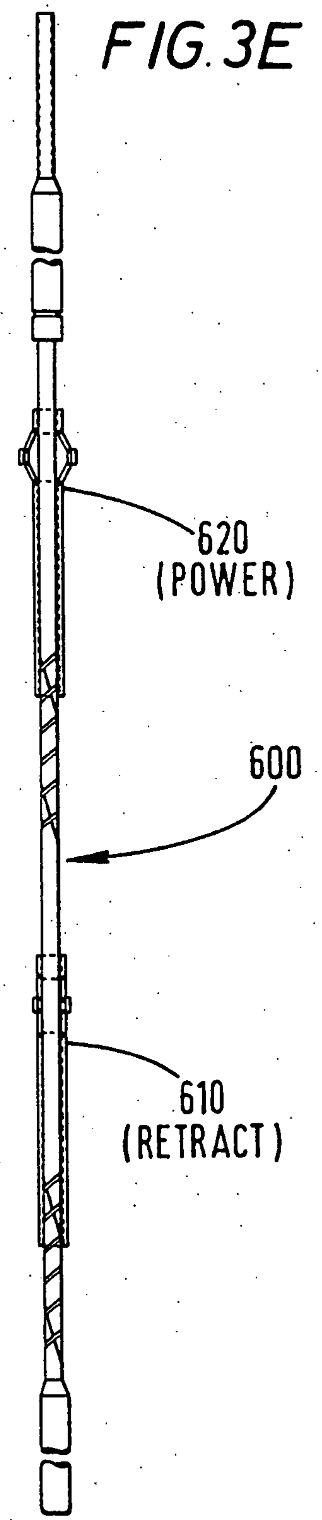
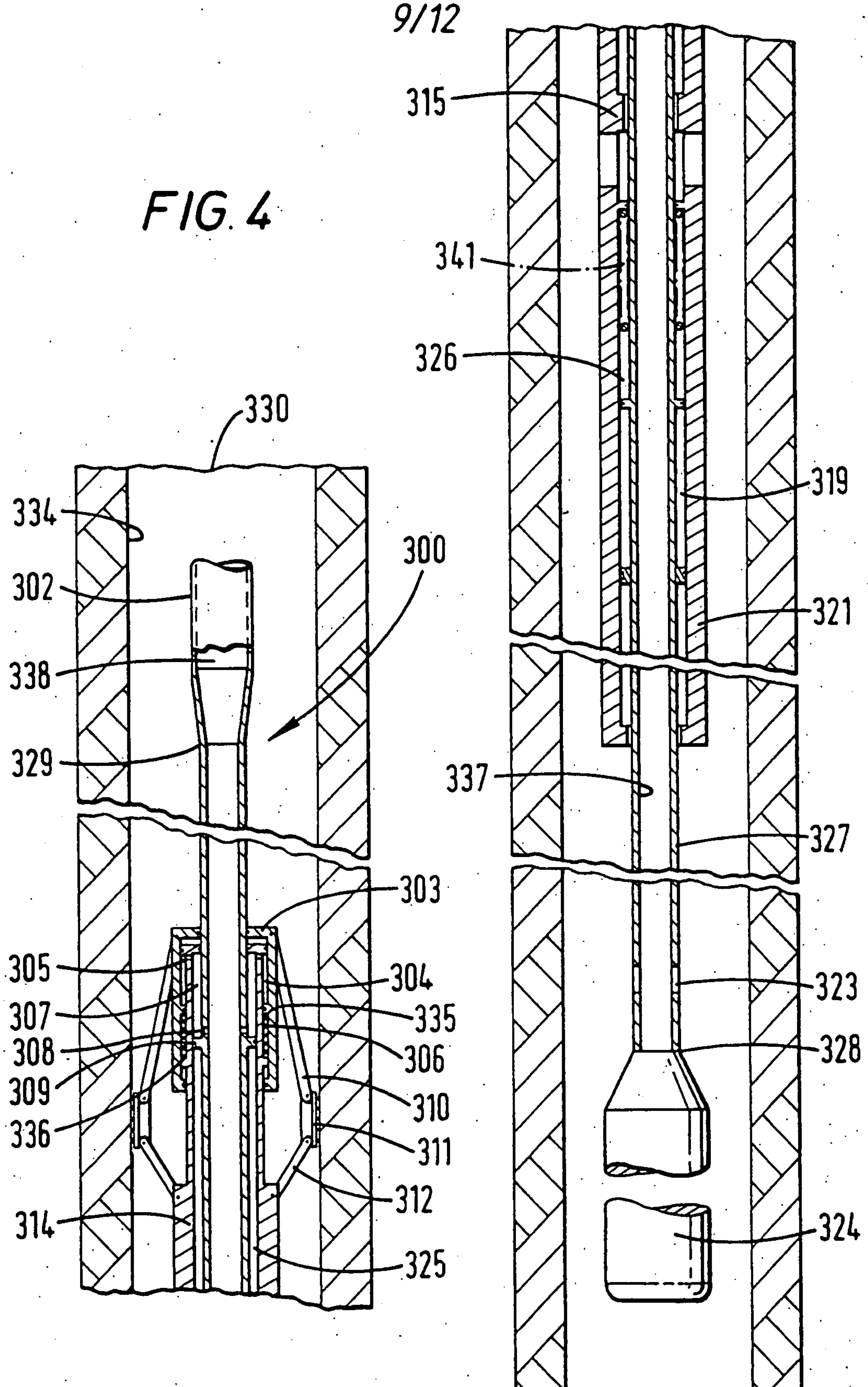


FIG. 4


330
334
302
338
329
300
303
305
304
307
335
308
306
309
310
336
311
312
314
325
315
341
326
319
321
337
327
323
328
324

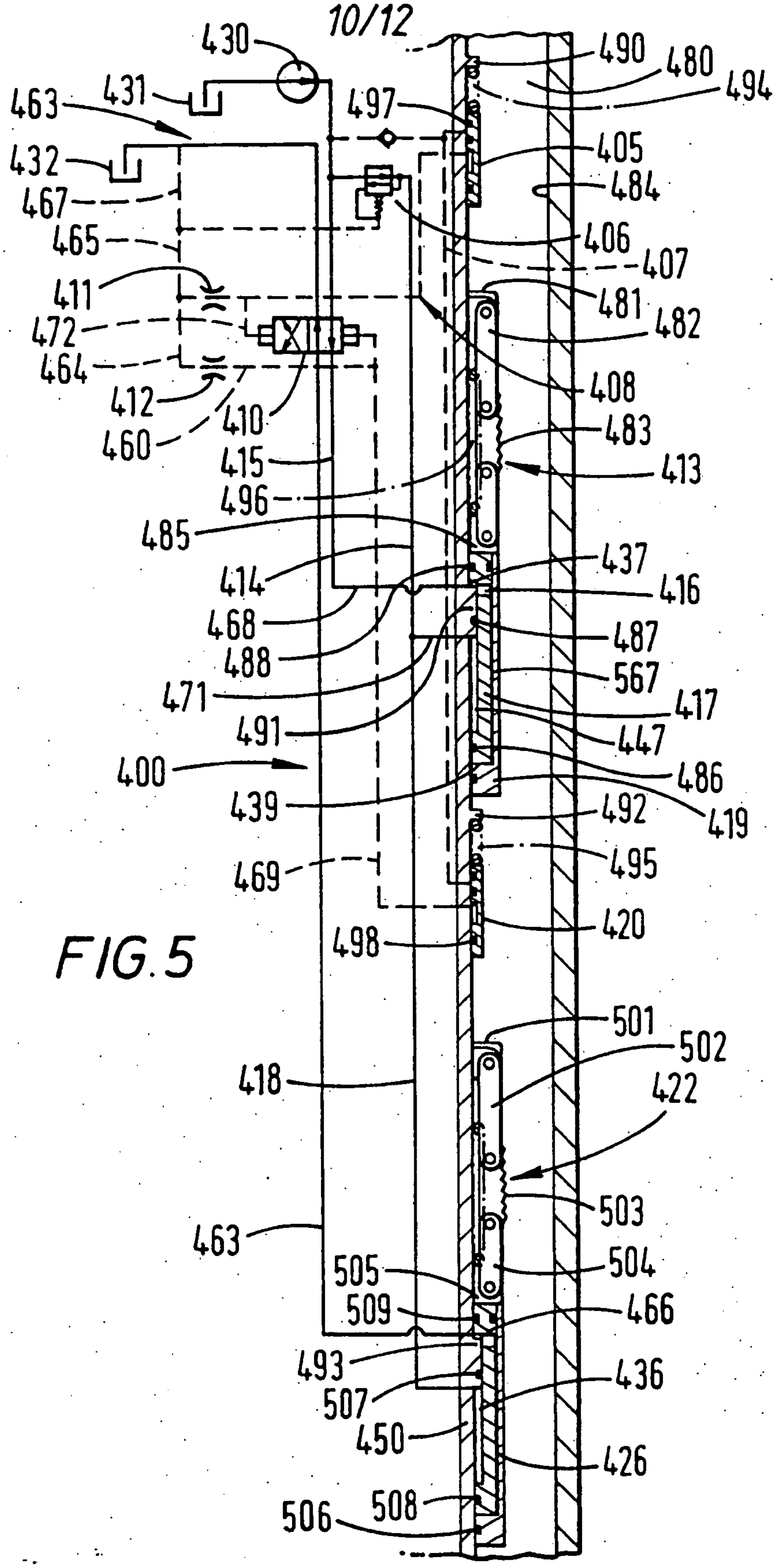

430
431
463
497
490
480
494
432
405
467
484
406
465
407
411
481
472
482
464
412
408
410
460
483
415
413
496
485
437
414
416
468
487
488
567
471
417
491
447
400
486
439
419
492
469
495
420
498
501
502
418
422
503
463
505
504
509
466
493
436
507
450
426
508
506

FIG.5

FIG. 6A

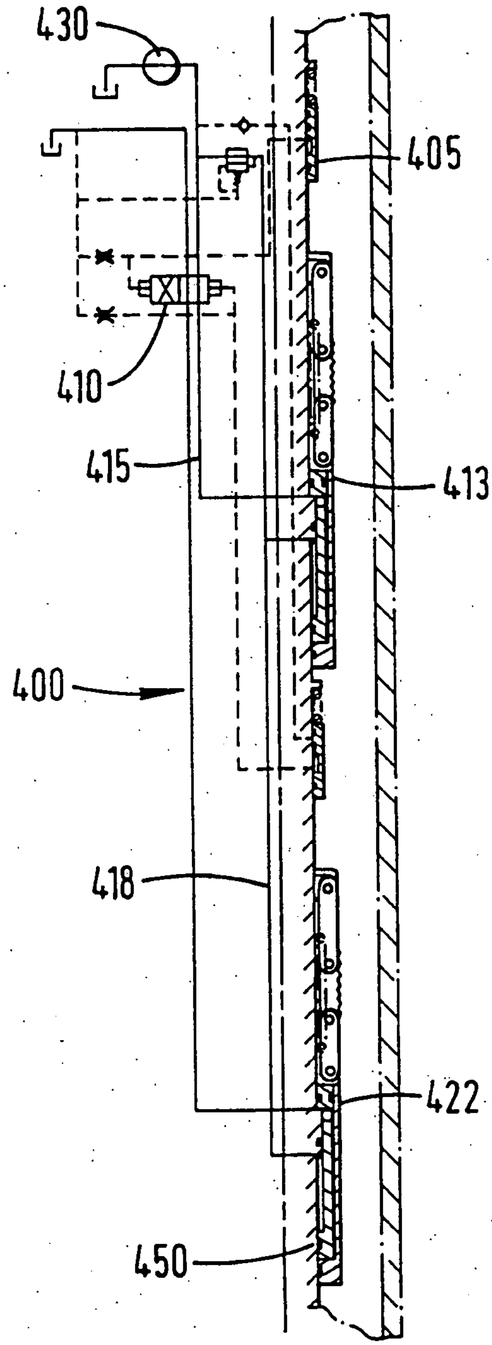

430
405
410
415
413
400
418
422
450

FIG. 6B

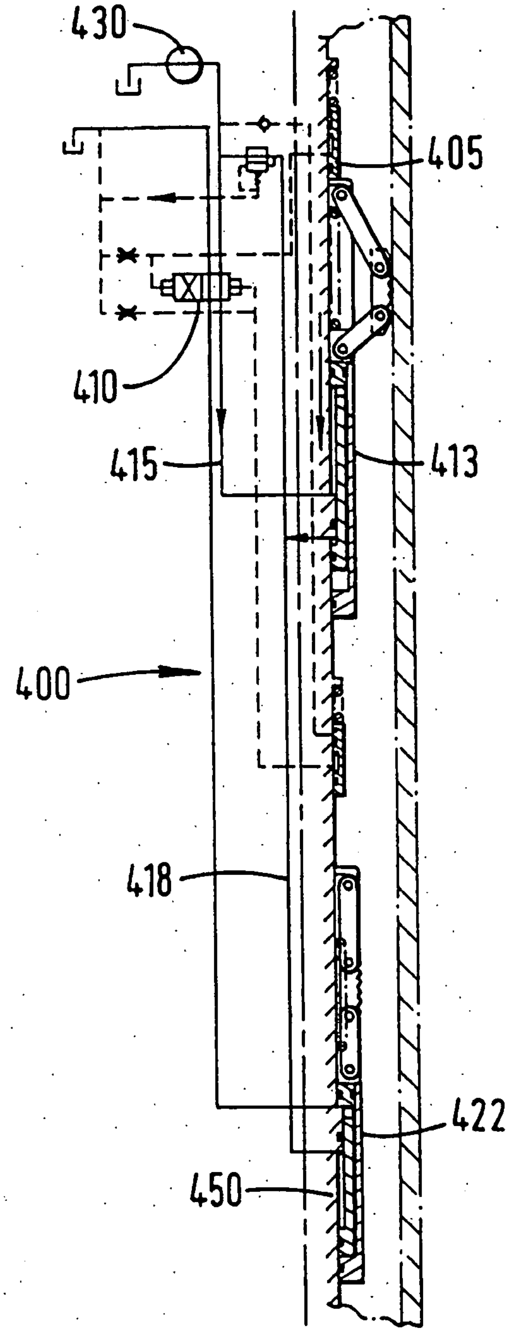

430
405
410
415
413
400
418
422
450

FIG.6C

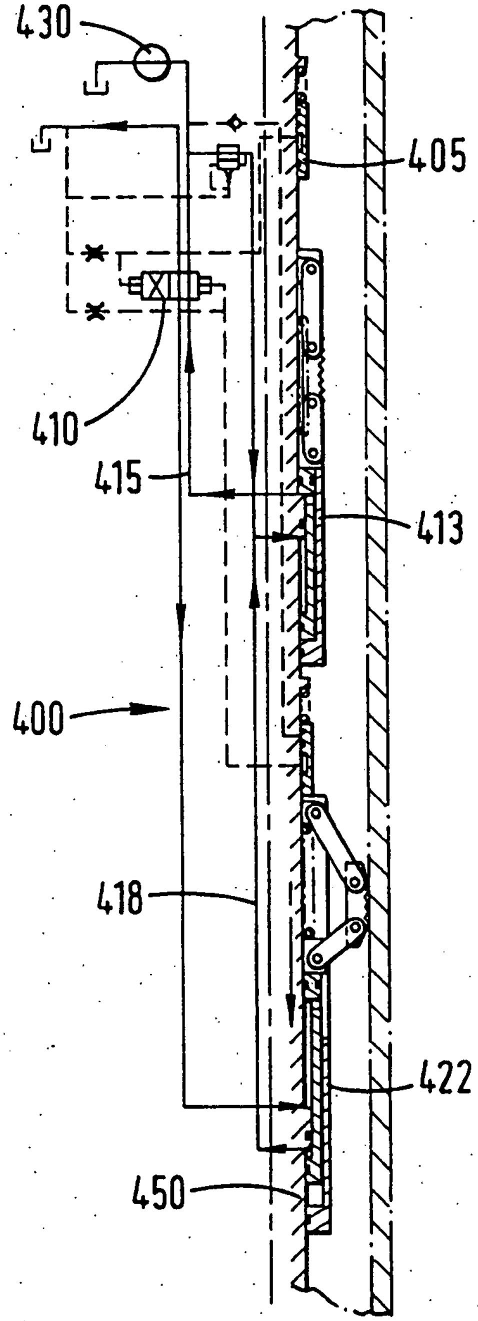
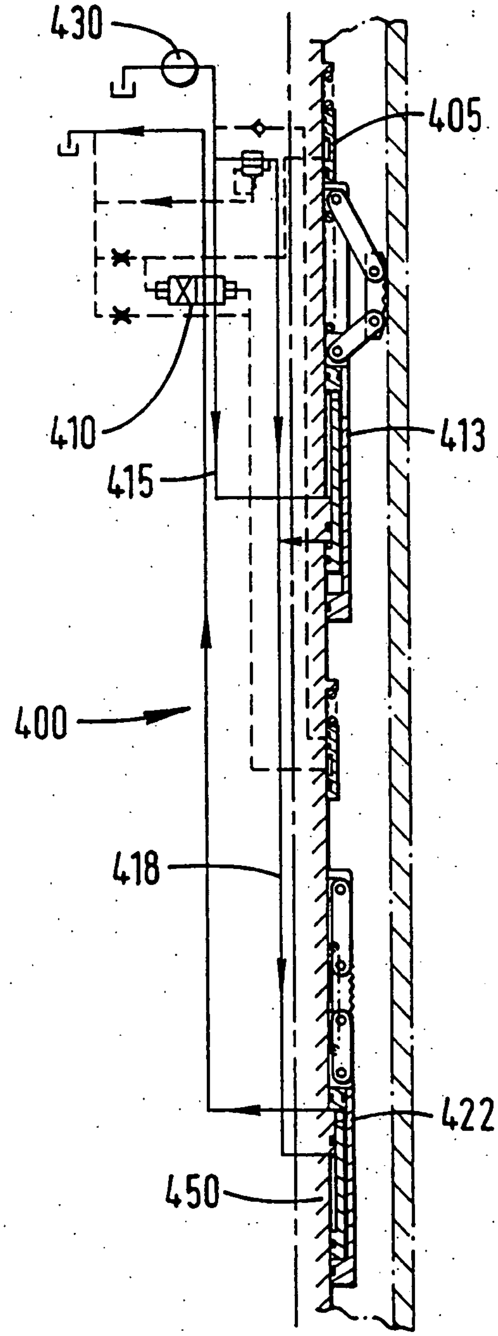

430
405
410
415
413
400
418
422
450

FIG.6D


430
405
410
415
413
400
418
422
450

# INTERNATIONAL SEARCH REPORT

Internal al Application No
PCT/GB 97/01868

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 6 E21B23/00 E21B23/04 E21B4/18

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 4 558 751 A (HUFFAKER) 17 December 1985<br>see column 6, line 9 - line 47<br>--- | 1,4,8,9 |
| X | EP 0 149 528 A (BRITISH GAS CORP.) 24 July 1985<br>see page 5, paragraph 2<br>----- | 1,4,8,9 |

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 24 October 1997 | 31.10.97 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: (+31-70) 340-3016 | Rampelmann, K |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

Intern. al Application No
PCT/GB 97/01868

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| US 4558751 A | 17-12-85 | NONE | |
| EP 149528 A | 24-07-85 | AU 552780 B | 19-06-86 |
| | | AU 3768985 A | 25-07-85 |
| | | CA 1226532 A | 08-09-87 |
| | | DE 3560799 A | 26-11-87 |
| | | GB 2153040 A,B | 14-08-85 |
| | | JP 60175892 A | 10-09-85 |
| | | US 4674914 A | 23-06-87 |